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PATENTS ACT, 1949

AMENDED SPECIFICATION

Reprinted as amended under Section 29 on 24 August 1971 also corrected under Section 76 on 31 January 1967.

PATENT SPECIFICATION

1016,245



NO DRAWINGS

1016,245

Inventor: MICHAEL EDWARD BENET JONES

Date of filing Complete Specification (under Section 3 (3) of the Patents Act 1949): Oct. 24, 1963.

Date of Application (No. 41976/62): Nov. 6, 1962.

Date of Application (No. 10592/63): March 18, 1963.

Complete Specification Published: Jan. 5, 1966.

Index at acceptance:—C3, A7P

Int. Cl.:—C 08 g

COMPLETE SPECIFICATION

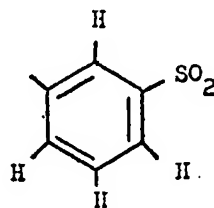
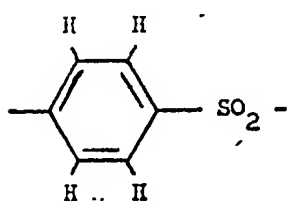
Manufacture of Polysulphones

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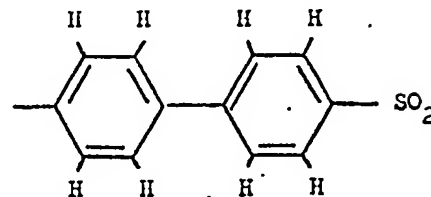
AMENDED SPECIFICATION NO. 1,016,245

Page 7, line 22, for 364.24 read 367.24

Page 13, lines 20 to 24, should read



and/or



THE PATENT OFFICE  
21 March 1972

R 9040/1

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COMPLETE SPECIFICATION

Manufacture of Polysulphones

We, IMPERIAL CHEMICAL INDUSTRIES LIMITED, of Imperial Chemical House, Millbank, London, S.W.1., a British Company, do hereby declare the invention, for which we

5 pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

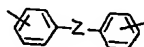
10 This invention relates to new polymeric materials containing sulphone groups in the polymer chain.

According to our invention we provide new thermoplastic polymeric materials consisting essentially of repeating units having the struc-

15 
$$-\text{Ar}-\text{SO}_2-$$

where Ar is a divalent residue which may vary from unit to unit in the polymer chain and in at least some of the units Ar has the

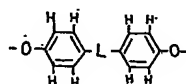
20 structure I



(I)

(where Z is an oxygen or sulphur atom or the

residue of a 4,4'-bisphenol having the structure II



25

wherein L is  $-\text{CO}-$  or  $-\text{SO}_2-$  (II) and in any other unit Ar is a residue of benzene, diphenyl, or a polynuclear aromatic hydrocarbon containing not more than two aromatic nuclei, so that in the divalent aromatic residues containing two benzene rings each benzene ring bears one of the valencies, and one or more of the aromatically bound hydrogen atoms in any of the divalent aromatic residues may be replaced by halogen atoms or alkyl or alkoxy groups containing from 1 to 4 carbon atoms. By a polynuclear aromatic hydrocarbon we mean a hydrocarbon containing two or more condensed rings of which at least one is aromatic. Examples are indene, naphthalene and fluorene. On the whole, we prefer those polymers in which none of the aromatically bound hydrogen atoms have been replaced with other atoms or groups because of their remarkable inertness to aqueous acid

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or alkaline chemicals even at very high temperatures.

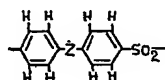
As a further feature of our invention we provide polymers having repeating units of the structure  $-\text{Ar}-\text{SO}_2-$  as hereinbefore defined and units of the structure



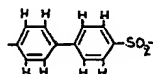
where Ar has the possibilities listed above. Polymers containing units of the structure  $-\text{Ar}-\text{CO}-$ , even when Ar comprises two benzene nuclei linked by a bridging group, tend to be crystalline in character.

The polymeric materials of the invention are of high softening point and of excellent thermal stability at high temperature even above their softening points. The amorphous polymers of this group are soluble in a number of organic solvents, are strong and frequently transparent, and are stable for long periods in molten form. They are, therefore, eminently suitable for fabrication by suitable plastics shaping processes, for example injection and compression moulding and extrusion.

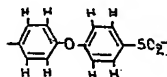
Our preferred polymers, which are particularly suitable for moulding, consist essentially of repeating units having the structure



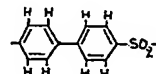
and optionally also units having the structure



Particular examples of such polymers are those containing units having the structure



and optionally also units having the structure



In general, we have found that increase of the number of units having the latter structure increases the softening point of our preferred copolymers but also endows them with an increasingly brittle nature; polymers in which these units comprise more than 80% of the total number of units tend to be crystalline, insoluble and fabricated only with difficulty by standard plastic shaping processes. Those containing about 30% of such units have a very suitable combination of softening point and tensile properties.

Our specified polymers have remarkably high softening points, frequently of the order of 300°C or higher, are thermoplastic and, after treatment to prevent them setting-up are stable for long periods in the melt. The amorphous polymers are particularly suitable for fabrication at their softening point without degradation to give shaped products which are generally strong, transparent and inert to a wide variety of chemicals, both acid and alkaline, even at temperatures near their softening point. They may be melt spun to yield fibres and filaments which may be used in applications where resistance to chemical and high temperatures is desired, for example in the manufacture of protective clothing, and they may be extruded to give strong, transparent films which can withstand flexing and are suitable for wrapping or in electrical applications where their high softening points are particularly advantageous. They may be shaped by any suitable process to give, hard, strong, transparent mouldings having good stability to thermal degradation at temperatures as high as 300°C. The shaped products may be used, for example, as electrical insulants, for instance in transformer parts, switch gear and condensers.

Many of the products are soluble in polar organic solvents, for example nitrobenzene and dimethyl formamide. Fibres and films may be formed from the solutions and coatings deposited from the solutions, e.g. on wire, give good electrical insulation. The coated products may be used in conditions where elevated temperatures are encountered, for instance in electrical transformers and high voltage switch gear. Those of our products with molecular weights equivalent to reduced viscosities (measured on a solution of 1 gm. of the polymer in 100 ccs. of dimethyl formamide at 25°C) of 0.6 or more have a combination of physical properties (for example tensile strength, modulus and softening point) that makes them particularly suitable as moulding materials. We prefer polymers that are to be used in applications which make use of their strength to have reduced viscosities of at least 1.0.

The polymers show good adhesion to surfaces of glass and metals and adhere particularly well to glass. Thus, they may be used as high temperature thermoplastic adhesives for joining metal (e.g. stainless steel) parts, for example, in the manufacture of household goods (e.g. ovens and irons).

The polymers may be mixed with other suitable ingredients such as dyes, pigments, heat and light stabilisers, plasticisers, mould-release agents, lubricants and fillers and may be blended with other polymeric materials if desired.

We provide a process for manufacturing polysulphones consisting essentially of repeating units having the structure



as defined above which comprises melting together at least one first compound



containing two aromatically bound sulphonyl halide groups and at least one second compound  $\text{H}-\text{Ar}-\text{H}$  which contains at least two aromatically bound hydrogen atoms, where  $\text{X}$  is a halogen atom and  $\text{Ar}$  conjointly in the first and second compounds is as defined above, in the presence of from 0.05% to 5% by weight of the compounds of a salt of iron which is soluble in the polymerisable mixture or antimony pentachloride.

According to a modification of the process, at least one single organic compound containing a sulphonyl halide group and a hydrogen atom each bound to an aromatic ring may replace the combination of the aforementioned first compound and second compound.

The first compound in our two-component process will have two sulphonyl halide ( $-\text{SO}_2\text{X}$ ) groups each attached to an aromatic nucleus.

We prefer the substituents, if any, to be *meta* to the  $\text{SO}_2\text{X}$  groups since substitution in the *ortho* positions tends to cause steric hindrance to the polymerisation.

Substituent groups containing active hydrogen atoms (for instance, amine, mono-substituted amine, thiol and hydroxyl groups) tend to react with the polymerisation catalysts and sulphonyl halide groups and must therefore be absent. Examples of benzene and substituted-benzene disulphonyl chlorides are benzene-1,3-disulphonyl chloride; toluene-2,4-disulphonyl chloride; toluene-3,5-disulphonyl chloride; chlorobenzene - 2,4 - disulphonyl chloride, anisole-3,5-disulphonyl chloride and benzene-1,4-disulphonyl chloride.

We have found in general that where our specified first compound has both its sulphonyl

halide groups attached to the same benzene ring, the polymerisation process is undesirably slow and we prefer, therefore, to use those compounds in which  $\text{Ar}$  is a diphenyl residue or has the structure I so that each benzene ring bears one sulphonyl halide group. We find it most convenient to use the 4,4'-disulphonyl chloride derivatives because of their availability. We further prefer that in the aromatic nuclei only the hydrogen atoms *ortho* to the bridging group are substituted by other atoms or groups.

The second compound in our two component process may be any aromatic compound  $\text{H}-\text{Ar}-\text{H}$  having  $\text{Ar}$  as hereinbefore described. Where the aromatic compound comprises a single benzene ring it may have up to four substituents and in diphenyl or the structure I each benzene ring may contain up to five substituents (including the bridging group) thus leaving in all cases at least two hydrogen atoms attached to aromatic nuclei.

Where substituted aromatic compounds are chosen, the preferred types and positions of the substituents on the aromatic nuclei are as described above for the disulphonyl halide compounds.

In general, we have found that if benzene or a substituted benzene is chosen as the second compound in our two-component process, the reaction is very slow and therefore we prefer to use those second compounds in which  $\text{Ar}$  is a diphenyl residue or has the structure I.

Examples of first and second compounds are diphenyl, diphenyl ether, diphenyl sulphide, di-2-chlorophenyl sulphide, di-2-methoxyphenyl ether, 2-phenoxytoluene, di-3,5-dichlorophenyl ether, di-*o*-tolyl ether, and 4,4'-diphenoxydiphenylsulphone, and their 4,4'-disulphonyl chlorides.

Mixtures of our specified first and second compounds may be polymerised to give mixed polymers if desired. By careful choice of the ingredients, considerable variation of the physical properties of the polymeric products may be achieved. In general, it is preferred to use equimolar amounts of first and second components. However, where it is desired to limit the molecular weight, this may be done by adding an excess of one or other of the components. Alternatively such molecular weight control may be effected by adding to the polymerisation a monofunctional compound. By a monofunctional compound we mean one which has only one active atom or group under the conditions of the reaction. An example is a 3,5-disubstituted benzene sulphonyl halide (e.g. 3,5-dichlorobenzene sulphonyl chloride).

The disulphonyl halide compound or compounds used in the polymerisation may be re-

placed in part by one or more compounds containing two carbonyl halide groups each of which is bound to an aromatic nucleus. Such compounds may have the formula



where Ar is as described above and X is halogen. The preferences for these carbonyl halide compounds are in general the same as those for the disulphonyl halide compounds and the products obtained from such a polymerisation are mixed polymers containing  $-CO-$  and  $-SO_2-$  groups in the polymer chains. Products having a wide variety of physical properties may be obtained by varying the choice and concentrations of the compounds taking part in the polymerisation reaction. However, those containing groups derived from dicarbonyl halides generally tend to be crystalline.

20 In our modified process wherein the combination of first and second compounds is replaced by a single compound as described hereinbefore, aromatic compounds.



25 having Ar as hereinbefore described, containing both an aromatically bound sulphonyl halide group and an aromatically bound hydrogen atom, may be used. The rules for the preferred choice of such compounds are the same as for the first and second compounds of our two-component process.

30 Mixtures of these mono-sulphonyl halide compounds, to give mixed polymers, may be used if desired and where such mixtures are used, this modified process is particularly suitable because of its flexibility. Aromatic mono-carbonyl halides of similar form may also be copolymerised with these sulphonyl halide compounds to give mixed polymers. 35 Limitation of the molecular weight of the products of this modified process may be obtained, where desired, by the addition to the polymerisation mixture of a monofunctional compound as hereinbefore defined.

45 It will be appreciated that an equimolar mixture of our specified first and second compounds may also be reacted with one or more of our specified monosulphonyl halides to give high polymeric products. Variation of the mixture of first and second compounds from equimolar proportions will tend to reduce the molecular weight.

50 The polymerisation may be effected by heating together the component or components and the catalyst alone. The presence of solvents generally slows down the reaction and also, since only the low polymers tend to be soluble in the solvents, the products are generally only of low molecular weight. 55 Furthermore, use of a solvent is economically

unattractive and therefore we work in its absence.

In our two-component process, we prefer that the disulphonyl halide compounds and the second components be added in approximately equimolar proportions. However the proportions may be varied from equimolar quantities where it is desired to restrict the molecular weight of the products. In the modified process, where two or more components are used they may be added in any desired proportions.

Suitably, the polymerisable component or components are heated until molten and thoroughly mixed before the catalyst is added to the melt. As polymerisation continues the temperature is raised in order to maintain the ingredients in the molten state and when the maximum required temperature is reached, this is maintained for a further period of time, generally of the order of 2 to 3 hours in order to allow completion of the polymerisation. During the polymerisation, hydrogen chloride is evolved and must be removed, e.g. by effecting the reaction under vacuum. The reaction is preferably conducted in the presence of an inert gas such as nitrogen in order to ensure the absence of oxygen above the melt. Where it is desired to obtain polymer of high molecular weight within a reasonable time period, temperatures of 200°C or more are generally required.

The catalysts used in the polymerisation are iron salts which are soluble in the polymerisable mixture or antimony pentachloride; the salts may be those of ferrous or ferric iron. Because the molecular weights of the polymers formed by this process generally increase with increase in the temperature at which polymerisation is effected, it is preferred to use catalysts which do not dissociate to inert products even at the higher temperatures of from 200 to 250°C. Antimony pentachloride tends to dissociate at about 170°C and is therefore ineffective in producing high molecular weight products.

Examples of iron salts that may be used are ferric fluoride, ferric chloride, ferrous bromide, ferrous iodide, ferric orthophosphate and ferrous and ferric acetoacetates. In general, we prefer to use the iron halides because of their useful catalytic activity and ferric chloride is particularly preferred because of its ready solubility in a wide variety of solvents, the ease with which it may be obtained in very pure form and because its use under suitable conditions consistently gives polymers of high molecular weight.

The catalysts are used in amounts of from 0.05% to 5% by weight of the polymerisable ingredients. Generally, amounts of less than 0.05% induce only very slow polymerisation but it is preferred to use not more than 1% by weight of catalyst because of the difficulty

in removing the catalyst residues from the polymer. Amounts of from 0.1 to 0.5% are preferred.

As we have already stated, the high molecular weight polymers (which in general are those having the better all-round physical properties) are obtained within a reasonable period of time by effecting the polymerisation at high temperatures, generally of the order of 200°C or above. This is because increase of molecular weight is accompanied by increase in softening point of the polymer and when the molecular weight of the polymer formed during the polymerisation becomes such that its softening point attains or surpasses the polymerisation temperature, the reaction mass will tend to solidify and polymerisation will then proceed only very slowly, if at all. However, we have now found that there is an undesirable tendency for the polymers to cross-link if they are subjected to certain temperatures, generally above 250°C, during polymerisation. On the other hand, only if the polymerisation temperature is maintained at or above 250°C are products of good physical strength consistently obtained. The cross-linked polymers are generally insoluble in all common solvents and tend to be intractable. They are therefore by products of little value as moulding, solvent-spinning or solvent-casting materials.

Therefore, we provide an improved process for obtaining polymers of high molecular weight in which the polymerisable material is subjected in the presence of the catalyst to a temperature above its melting point but below that at which substantial cross-linking of the polymeric product would occur until the mixture becomes viscid or solid; cooling it, comminuting the cooled mixture, and thereafter reheating the comminuted product to a temperature below that at which substantial cross-linking would occur in order to complete the polymerisation.

In our preferred process the polymerisable material is charged into the polymerisation vessel and heated until it is molten. Where two or more compounds are used, they are thoroughly mixed together when molten. The polymerisation catalyst is then dissolved in the melt. In general, there is a short induction period and then rapid evolution of hydrogen halide (generally hydrogen chloride gas) denotes the commencement of polymerisation.

Since some of the reagents in the polymerisation process may react with water it is preferred, where products of high molecular weight are required, rigorously to exclude moisture from the reaction vessel during the polymerisation and, in our improved process, during the comminution step. It is also preferred to effect the reaction in the absence of air, for example by evacuating the reaction vessel or purging it with an inert gas (for example nitrogen) or both.

The course of the polymerisation may be followed by measuring the evolution of hydrogen halide.

After the addition of the catalyst, the molten mixture is maintained at an elevated temperature until it becomes a highly viscous mass or solidifies. In general, we have found that the polymeric material tends to cross-link if the polymerisation medium is subjected to temperatures above about 250°C and therefore we prefer not to work above this temperature. In order to ensure that no cross-linking occurs to give insoluble by products, we prefer to operate the first stage stage of the polymerisation process at or below 200°C until the product becomes viscid or solid.

The rapid increase in viscosity and eventual solidification of the melt is caused by the polymers attaining a molecular weight which gives them a softening point above the temperature of the polymerisation mixture. The time before solidification occurs depends upon the temperature of the melt: increase in temperature generally resulting in a reduction in the time required. Therefore we prefer to use as high a temperature as possible without cross-linking occurring. Temperatures of from 150 to 200°C have been found generally suitable.

The melt generally forms a viscid or solid foamed mass in the reaction vessel and this mass is then cooled and ground to a fine powder. The comminution is effected under anhydrous conditions in order to avoid destroying the catalyst. Any suitable grinding means may be used. The fine powder is then reheated and maintained at an elevated temperature below that at which cross-linking would occur until polymerisation is complete. It is preferred that this heating step is effected under reduced pressure in order to aid the removal of the hydrogen chloride gas. Temperatures of from 150°C to 250°C are very suitable. The time required for the second heating step also depends upon the temperature of the heat treatment, higher temperatures requiring shorter times. Times of from 15 minutes to a few hours are normally very suitable, depending on the molecular weight required and the scale of the reaction. The end of the reaction is generally indicated by the cessation of evolution of hydrogen halide gas.

After the polymerisation, it is preferred to remove the catalyst residues from the product since their presence may cause discolouration and sometimes degradation. Any suitable process may be used. For example, the polymer may be ground down to powder and treated with hydrochloric acid in an alcohol, preferably methanol, under reflux. However, this process is frequently inadequate and removes only small amounts of the catalyst. Therefore we prefer to dissolve the polymer in a suitable solvent (for example di-

methanol formamide or nitrobenzene) and treat it in solution with a complexing agent, preferably a chelating agent, for the catalyst. The complex is then separated from the polymer. The treated polymer may be re-precipitated by pouring the filtered solution into a suitable non-solvent for the polymer (for example an alcohol, preferably methanol, or acetone) and is then thoroughly dried, preferably at elevated temperature and preferably under vacuum.

The products often tend to suffer from "setting-up" during processing operations which necessitate holding the polymers at elevated temperatures and particularly in molten form. It is believed that this "setting-up" which may be recognised by an increase in the viscosity of the melt, is due to decomposition of terminal sulphonyl or carbonyl halide groups to yield active points in the polymer chain. These active points precipitate a cross-linking reaction which may ultimately reduce the polymer to an insoluble, infusible mass which is useless for normal fabrication processes in plastic art, such as injection moulding, compression moulding or extrusion. The process of "setting-up" may be substantially reduced or eliminated entirely by reacting the polymers in solution and below the temperature at which "setting-up" would occur with an organic compound having one or two groups per molecule which will react with the sulphonyl halide or carbonyl halide groups in the polymer to yield products which are stable at temperatures at which the polymer is molten. Suitable compounds are aromatic amines, particularly aniline, and the process may suitably be effected before, after or during the process for removing the catalysts from the polymer. In such cases, any excess of the compound may be removed from the polymer at the same time as the catalyst complexes.

The products of the process are polymers containing repeating units wherein a sulphone group is tied to two aromatic residues. The un-crosslinked products are thermoplastic materials, generally of high softening point, which may be used in any suitable process known for fabricating plastic material. Those of high molecular weight may be tough solids which are substantially inert to a wide variety of chemicals, both acid and alkaline. They may be melt-spun to give fibres and filaments or cast from solution in suitable solvents to give films. They may be admixed with other suitable ingredients, (for example pigments, heat and light stabilisers, plasticisers, lubricants, mould-release agents and fillers) and may be blended with other polymeric materials if desired.

Where these polymers are formed by our specified two component process, e.g. using a disulphonyl halide compound of the structure  $X \cdot SO_2-Ar-SO_2 \cdot X$  and a second

compound having the structure  $H-Ar'-H$  (where  $Ar'$  has the same possibilities as  $Ar$ ), they will have repeating units of the structure  $-Ar-SO_2-Ar'-SO_2-$  but where they are formed from our modified process using one or more compounds each having a single aromatically bound sulphonyl halide group and an aromatically bound hydrogen atom, they will comprise randomly distributed units of the structure  $-Ar-SO_2-$  where  $Ar$  may vary from unit to unit in the chain.

It will be appreciated that in the first mentioned process two or more disulphonyl halide compounds of the general structure  $X \cdot SO_2-Ar-SO_2 \cdot X$  may be reacted with one or more aromatic compounds of the general structure  $H-Ar'-H$ , and that in both processes at least some of the polymerisable molecules contain the structure I.

The configuration of the repeating units varies slightly with the process of manufacturing the polymer. For example, the use of the single reagent diphenyl ether 4-sulphonyl chloride gives a polysulphone of essentially the all-*para* configuration, and the use of the two reagents diphenyl ether 4,4'-disulphonyl chloride and diphenyl ether gives a polysulphone in which a small proportion (in some cases up to 20%) of the units have the sulphonyl group *ortho* to the oxygen atom (although diphenyl ether 4,4'-disulphonyl chloride and 4,4'-diphenoxydiphenylsulphone give an all-*para* polysulphone). The polymer made in either of these ways may also be slightly branched.

The invention is illustrated by the following Examples in which all parts are expressed as parts by weight.

#### EXAMPLE 1

734.84 parts (2 moles) of diphenyl ether-4,4'-disulphonyl-chloride were fused with 308.52 parts (2 moles) of diphenyl at 90°C. under a slow stream of nitrogen in a heated vessel and after stirring for 30 minutes, 4 parts of freshly sublimed ferric chloride were added to the melt. The catalyst dissolved rapidly on stirring with vigorous evolution of hydrogen chloride. The reaction temperature was raised rapidly but the mixture solidified at a bath temperature of about 180°C. The reaction temperature was raised further to 280°C. at which temperature the mixture was still solid. The total reaction time was 40 minutes.

The mixture was allowed to cool and the product was then broken up and stirred with 7850 parts of boiling isopropanol. The insoluble product was filtered off and the process was repeated twice. On drying, the yield was 880 parts of a polymer having a reduced viscosity measured as a 1% solution in dimethyl formamide at 25°C of 0.15. The polymer was shown to be amorphous by X-ray examination and could be solvent cast from dimethyl formamide to give transparent films.

## EXAMPLE 2

550.64 parts (1.5 moles) of diphenyl ether-4,4'-disulphonyl chloride, 137.76 parts (0.5 mole) of benzene-1,3-disulphonyl chloride and 307.56 parts (2 moles) of diphenyl were fused together at 90°C under a slow stream of nitrogen in a heated vessel. After stirring for 30 minutes, 6.5 parts of ferric chloride were added and vigorous evolution of hydrogen chloride began. The reaction temperature was raised until after a further 20 minutes it reached 280°C. It was then raised slowly to 300°C and held there for 40 minutes. The total reaction time was 95 minutes.

The product was treated as for Example 1 to give 870 parts of a clear, tough polymer having a reduced viscosity of 0.30. The polymer was shown to be amorphous by X-ray examination and could be solvent cast to give strong films.

## EXAMPLE 3

364.24 parts (1 mole) of diphenyl ether-4,4'-disulphonyl chloride, 275.17 parts (1 mole) of benzene-1,3-disulphonyl chloride and 308.40 parts (2 moles) of diphenyl were fused and stirred at 100°C under a slow stream of nitrogen. After 10 minutes 2 parts of ferric chloride were added. There was brisk evolution of hydrogen chloride. Over a period of 1 hour, the temperature of the reaction was raised to 320°C at which temperature the product was a very viscous liquid. The mixture was held for a further 45 minutes at 320°C under a vacuum of 0.7 mm. of Hg and then cooled.

The product was ground to a fine powder, dissolved in a hot mixture of 9530 parts of dimethyl formamide and 195.2 parts of acetyl acetone and filtered into a stirred excess of ethanol to precipitate the polymer. The product was 520 parts of a polymer which was found to be insoluble in cold solvents. The rather low yield in this and following Examples 4 to 10 is due to a certain amount of cross-linking occurring at the high temperatures of the polymerisation, yielding some insoluble polymer which was removed during the filtration step.

## EXAMPLE 4

735.12 parts (2 moles) of diphenyl ether-4,4'-disulphonyl chloride, 154.20 parts (1 mole) of diphenyl and 170.20 parts (1 mole) of diphenyl ether were fused at 120°C under a slow stream of nitrogen. 2 parts of ferric chloride were added and the mixture stirred to dissolve the catalyst. There was vigorous evolution of hydrogen chloride. The polymerisation and treatment of the polymer were as for Example 3 and the yield was 620 parts of a polymer insoluble in cold solvents.

## EXAMPLE 5

769.16 parts (2 moles) of diphenyl ether-4,4'-disulphonyl chloride and 356.72 parts (2

moles) of diphenyl ether were fused and stirred at 100°C under a slow stream of nitrogen. After 10 minutes, 1.7 parts of ferric chloride were added and there was brisk evolution of hydrogen chloride. The polymerisation and treatment of the polymer was as for Example 3 and the yield was 820 parts of a polymer having a reduced viscosity of 0.61 and a softening point of about 320°C.

## EXAMPLE 6

The process of Example 5 was repeated and the product was ground to a fine powder, dissolved in a hot mixture of dimethyl formamide and acetyl acetone and filtered into a stirred excess of acetone to precipitate the polymer. A polymeric product was obtained having a reduced viscosity of 0.76 and a softening point of about 320°C.

## EXAMPLE 7

735 parts (2 moles) of diphenyl ether-4,4'-disulphonyl chloride and 340 parts (2 moles) of diphenyl ether were fused together at 100°C and stirred for 10 minutes under a slow stream of nitrogen. 3.3 parts of ferric acetoacetate were then added to the mixture and the temperature of the whole was raised slowly over a period of 4 hours 15 minutes to 290°C. The mixture was then subjected to a vacuum of 0.3 mm. of Hg and the temperature raised slowly to 320°C over a period of 25 minutes and held there for a further 20 minutes. The melt was then cooled and the resultant solid ground to a powder and stirred and refluxed with 7850 parts of isopropyl alcohol and 488 parts of acetyl acetone. The polymer was then filtered off, washed and dried to yield 580 parts of a polymer having a reduced viscosity of 0.28. The polymer was soluble in nitrobenzene and dimethyl formamide and could be solvent cast to give transparent films.

## EXAMPLE 8

The process of Example 7 was repeated using 10 parts of antimony pentachloride as catalyst. The temperature of the polymerisation was eventually raised to 340°C over a period of 3 hours 10 minutes and the product was a polymer having a reduced viscosity of 0.21.

## EXAMPLE 9

The process of Example 8 was repeated except that the fusion temperature of the mixture when the catalyst was added was 130°C and 48 parts of antimony pentachloride were used. The polymerisation temperature was maintained at 130°C for a further 34 minutes and then raised slowly to 310°C over a period of 2 hours. The melt was then subjected to a vacuum of 0.3 mm. of Hg for 10 minutes at 310°C before being cooled.

The solid product was ground to a powder and dissolved in 9530 parts dimethyl formamide and the solution was filtered into an



excess of methanol in order to precipitate the polymer. The precipitate was washed and dried at 80°C for 3 hours under vacuum to yield 520 parts of a polymer having a reduced viscosity of 0.32.

#### EXAMPLE 10

367.24 parts (1 mole) of diphenyl ether-4,4'-disulphonyl chloride and 402.42 parts (1 mole) of 4,4'-diphenoxy diphenyl-sulphone were fused together at 140°C and stirred under a slow stream of nitrogen for 10 minutes when 8 parts of ferric chloride were added as catalyst. The temperature was raised to 310°C for 2 hours after which a sample (Sample I) was removed from the melt. The remaining mixture was subjected to a vacuum of 0.3 mm. Hg for a further 45 minutes at 310°C before cooling to give Sample II.

Both the samples were worked up as described in Example 9 and Sample I gave a polymer with a reduced viscosity of 0.37 while that of Sample II was 0.47.

#### EXAMPLE 11

619.30 parts (2 moles) of chlorobenzene-2,4-disulphonyl chloride, 185.44 parts (1.2 moles) of diphenyl and 139.40 parts (0.8 mole) of diphenyl ether were fused at 140°C and stirred under a slow stream of nitrogen for 10 minutes before adding 4.1 parts of ferric chloride as catalyst as a 4.1% solution in tetrahydrofuran. The polymerisation temperature was raised slowly to 190°C over a period of 2 hours 15 minutes and to 230°C 20 minutes later when the product was still molten. The melt was cooled and the product ground to a powder, suspended in a mixture of isopropyl alcohol and acetyl acetone, reprecipitated and dried to give a black polymer.

#### EXAMPLE 12

2.7 parts of dry diphenyl ether-4-sulphonyl chloride (melting point 44°C) were fused in a closed vessel containing a nitrogen inlet and outlet under an atmosphere of dry nitrogen and 0.09 part of dry ferric chloride was dissolved in the molten monomer. Moisture was rigorously excluded from the reaction vessel. Evolution of hydrogen chloride gas commenced almost at once. After 7 minutes, the temperature was raised to 180°C and by that time 72% of the theoretical total amount of hydrogen chloride had been evolved. The reaction mixture, which had formed a very viscous foam, part solid, was cooled to a solid and powdered under an atmosphere of dry nitrogen and then the polymerisation was recommenced by heating the powder to 110°C. The temperature was raised to 180°C over a further 10 minutes when it was again reduced and the product again powdered. The reaction was continued by heating the powder initially to 150°C under high vacuum and thereafter to 240°C over a period of 15

minutes. The mass was held at this temperature for 20 minutes before being cooled, dissolved in 30 parts of dimethyl formamide and filtered. The polymer was precipitated by pouring the solution into a stirred mixture of 240 parts of acetone containing 30 parts of concentrated hydrochloric acid. The precipitated polymer was filtered, washed with methanol and dried overnight at 60°C under vacuum to give 1.8 parts of poly(p-sulphonyl diphenyl ether) having a reduced viscosity measured as a 1% solution in dimethyl formamide at 25°C of 1.2.

Samples of this polymer were compression moulded at 310°C and 20 tons per square inch pressure to form tough, transparent films of good quality which could be creased repeatedly without fracture.

The dynamic mechanical moduli of the polymer were measured at various temperatures by the cantilever vibration method at 100 cycles. The modulus dropped only slightly from  $3.8 \times 10^{10}$  dynes/cm<sup>2</sup> at -150°C to  $1.9 \times 10^{10}$  at +220°C.

#### EXAMPLE 13

2.8 parts of diphenyl ether-4-sulphonyl chloride were fused at 80°C under dry nitrogen and 0.085 part of ferric chloride was then added. Moisture was rigorously excluded from the reaction vessel. After 10 minutes the temperature was raised to 200°C when 68% of the theoretical amount of hydrogen chloride gas had been evolved. The mixture, which was in the form of a viscid foam, was cooled to a solid and powdered under dry nitrogen and polymerisation was recommenced by heating the powder to 100°C under an absolute pressure of 0.1 mm. of mercury. The temperature was raised rapidly to 220°C and held there for 2 hours then increased again to 240°C for a further 90 minutes after which the mass was cooled, dissolved in 30 parts of hot dimethyl formamide and filtered and the polymer was precipitated by pouring the solution into stirred chloroform. The precipitate was filtered, washed with methanol and dried for 1 hour at 200°C under high vacuum to give 1.8 parts of a polymer having a reduced viscosity of 1.35, measured as a 1% solution in dimethyl formamide at 25°C.

Clear, transparent films were cast from a 10% solution of the polymer in nitrobenzene and were found to be tough down to -60°C.

#### EXAMPLE 14

3.5 parts of diphenyl ether-4-sulphonyl chloride were fused at 80°C under dry nitrogen and 0.09 part of ferric chloride was added to the melt. Moisture was rigorously excluded from the reaction vessel. After 10 minutes, the temperature had been raised to 180°C and the reaction was 78% complete, calculated on hydrogen chloride evolution. The viscid foamed mass was cooled to a solid,

powdered and reheated to 150°C under high vacuum. The temperature was increased to 240°C over a period of ten minutes and held at a temperature of 240°C to 250°C for a further 30 minutes before cooling the mass. The cold polymer was dissolved in 40 parts of dimethyl formamide, precipitated by pouring the solution into 300 parts of well stirred 5N hydrochloric acid, filtered, washed with methanol and dried overnight at 60°C under vacuum to give 2.8 parts of a polymer having a reduced viscosity of 0.99 as measured as a 1% solution in dimethyl formamide at 25°C.

The melt viscosity of the polymer was measured at  $2.3 \times 10^5$  poises at a constant shear stress of  $8.2 \times 10^3$  dynes/sq. cm. at 350°C.

#### EXAMPLE 15

Using the process of Example 14, 2.9 parts of diphenyl ether-4-sulphonyl chloride were polymerised using 0.07 part of ferric chloride as catalyst. The temperature was raised to 170°C over 9 minutes when the polymerisation was calculated to be 67% complete by the measurement of hydrogen chloride evolution. The resultant highly viscous mass was cooled to a solid, powdered and reheated to 150°C. After 12 minutes at this temperature, the mass was cooled and powdered again and reheated slowly to 250°C under high vacuum over a period of 30 minutes. The mass was held at 250°C for a further 10 minutes, cooled and worked up by the method described in Example 14, to give 2.3 parts of a polymer having a reduced viscosity of 0.78 measured as a 1% solution in dimethyl formamide at 25°C.

#### EXAMPLE 16

33.3 parts of diphenyl ether-4-sulphonyl chloride were mixed with 0.8 part of freshly sublimed ferric chloride and heated to 200°C over 15 minutes and then held at 200°C for two hours with a slow stream of dry nitrogen passing over the reaction mixture. During this time 96% of the theoretical amount of hydrogen chloride was evolved. The product, which was a brown foamed mass, was powdered and then heated at 230—234°C under

an absolute pressure of 0.9 mm. of mercury for 5 hours. The resulting brown polymer was dissolved in 300 parts of dry dimethyl formamide and 1 part of aniline and shaken for 15 minutes. Four parts of 8-hydroxy quinoline-5-sulphonic acid were added and shaking continued for a further 30 minutes. The solution was then passed down a 10½ inch long, 1½ inch diameter column packed with Spence 100—200 mesh type H alumina. (The word 'Spence' is a registered trade mark.) The intense dark green iron complex was absorbed on the first 2 inches of the column. After the solution had been passed through the column, any adsorbed polymer was washed through with a further 150 parts of dimethyl formamide. The polymer was precipitated from the almost colourless solution by addition to 2500 parts of well stirred 5% aqueous hydrochloric acid. The white precipitate was filtered off, washed twice with 500 parts of distilled water and once with 250 parts of methanol and finally dried at 120° in vacuum for 16 hours to give 25.6 parts of polymer. Analysis showed that the polysulphone contained less than 20 parts per million of iron. The polymer could be held at 320°C for several minutes without any detectable increase in viscosity and clear, very pale yellow films were moulded from the product at 320°C.

#### EXAMPLE 17

35 parts of diphenyl ether-4-sulphonyl chloride were polymerised by the process described in Example 16 using 1.62 parts of ferric chloride as catalyst. The crude product was dissolved in 300 parts of dimethyl formamide at room temperature and the solution was dissolved into four equal parts each of which was shaken with one part of aniline for fifteen minutes. To each of three of the four parts was added the chelating agent disclosed in the table below and the four parts were each filtered through the alumina column described in Example 16 and the polymer was precipitated from each and worked up by the process described in Example 16. The results are set out below.

Solution	Additional Chelating Agent	Amount used (parts by weight)	Concentration of iron in polymer (ppm)
A	None	—	70
B	8-hydroxyquinoline-5-sulphonic acid	2.8	20
C	dimethyl glyoxime	0.7	30
D	ethylene diamine teraacetic acid	1.8	30

In each case the polymer obtained had a reduced viscosity of 0.72. All four samples could be held in the melt for long periods (up to 20 minutes or more) without any detectable increase in viscosity.

#### EXAMPLE 18

7.73 parts of diphenyl ether-4-sulphonyl chloride and 13.09 parts of diphenyl-4-sulphonyl chloride were fused together at 130°C under nitrogen. 0.39 part of ferric chloride was added to the melt and the temperature slowly raised to 180°C over a period of 26 minutes during which period 80% of the theoretical amount of hydrogen chloride was evolved. The foamed mass was cooled and powdered and the powder was reheated to 140°C under vacuum, and then heated further to 210°C over a period of 25 minutes. The mass was cooled and powdered again and heated once more to 120°C under vacuum. The temperature was raised to 240°C over a period of 12 minutes and held at 240–250°C for 130 minutes. The mass was then cooled, dissolved in 200 parts of dimethyl

formamide to which was added 2.0 parts of aniline and 1.8 parts of 8-hydroxyquinoline-5-sulphonic acid. The mixture was shaken for 20 minutes and then passed through the alumina column described in Example 16. The polymer was precipitated by pouring the solution obtained into dilute hydrochloric acid and was washed twice with hot methanol and dried for 18 hours at 100°C under vacuum to yield 16.7 parts of a copolymer having a reduced viscosity of 0.91 and a very high softening point, higher than 300°C and containing only 20 parts per million of iron.

An almost clear, colourless transparent film was cast from a solution of this polymer in nitrobenzene at 90°C.

#### EXAMPLE 19

A series of polysulphones was prepared following the process described in Example 18 but using varying amounts of diphenyl ether-4-sulphonyl chloride and diphenyl-4-sulphonyl chloride. Some properties of the products are set out below.

% diphenyl ether sulphone groups in copolymer (by I.R. analysis)	Form <sup>(1)</sup>	Modules <sup>(2)</sup> dynes/sq. cm.		Softening point
		–150°C	+200°C	
100	a. s.	$3.8 \times 10^{10}$	$1.9 \times 10^{10}$	about 240°C
84	a. s.	$2.6 \times 10^{10}$	$1.6 \times 10^{10}$	>250°C
74	a. s.	$3.9 \times 10^{10}$	$2.0 \times 10^{10}$	>250°C
43	a. s.	$2.1 \times 10^{10}$	$1.3 \times 10^{10}$	>250°C
23	a. s.	not measured		>250°C
0*	c. i.	$1.4 \times 10^{10}$	$1.2 \times 10^{10}$	>250°C

<sup>(1)</sup> a = amorphous

c = crystalline

s = soluble

i = insoluble

<sup>(2)</sup> Measured by the cantilever vibration method described by Robinson in J. Sci. Instruments 32, page 2, 1955.

\* This polymer did not foam during the polymerisation process.

All the amorphous copolymers could be solvent cast to give strong films but the films became more and more brittle with decrease in the amount of diphenyl ether sulphone radicals in the polymer.

## EXAMPLE 20

295 parts of diphenyl sulphide-4-sulphonyl chloride (melting point 73.5°C) were fused at 120°C under dry nitrogen and 5.4 parts of freshly sublimed ferric chloride were added to the melt. The temperature was raised to 180°C over a period of 12 minutes at the end of which time the amount of hydrogen chloride evolved was found to be 74% of theoretical. The product was cooled, powdered and heated under high vacuum at a temperature rising from 140°C to 230°C over a period of 14 minutes. The reaction mixture was finally held at 230—240°C for 105 minutes, thereafter cooled and dissolved in about 5000 parts of dimethyl formamide. 51 parts of aniline were added to the solution followed by 35 parts of 8-hydroxyquinoline-5-sulphonic acid. The mixture was shaken and then filtered through the alumina-packed column described in Example 16. The polymer was precipitated into dilute hydrochloric acid, washed with hot methanol and dried at 100°C under vacuum to yield 210 parts of a polymer having a reduced viscosity

(measured on a solution of 1 gm. of the polymer in 100 ccs. of dimethyl formamide at 50°C) of 0.56. X-ray examination showed the polymer to be amorphous.

## EXAMPLE 21

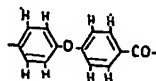
In each of a series of experiments 267 parts of diphenyl ether-4-sulphonyl chloride were heated with a catalyst (identified below) at 150°C for 40 minutes to yield a foamed mass which was cooled, powdered and reheated under high vacuum (about 0.2 mm. Hg absolute pressure) to a temperature of 230°C over a period of 15 minutes. The reaction mixture was finally held at 230°C for 1 hour before it was cooled, dissolved in about 3000 parts of dimethyl formamide and treated as described in Example 20 with 30.6 parts of aniline and 22 parts of 8-hydroxyquinoline-5-sulphonic acid. In each case the polymer obtained had a reduced viscosity (measured on a solution of 1 gm. of polymer in 100 ccs. of dimethyl formamide at 25°C) in the range of 0.1 to 0.2.

Experiment	Catalyst	Amount Used
A	Ferric orthophosphate	6.7 parts
B	Ferric fluoride	3.4 parts
C	Ferrous bromide	6.5 parts
D	Ferrous iodide	9.3 parts

## EXAMPLE 22

15.1 parts of 4-phenoxybenzoyl chloride (boiling point 146°C at 0.4 mm. Hg) and 27.1 parts of diphenyl ether-4-sulphonyl chloride (melting point 44°C) were heated to 130°C under a slow current of dry nitrogen. 1.4 parts of freshly sublimed ferric chloride were dissolved in the melt and the temperature was raised to 220°C over a period of 75 minutes when it was found that 79% of the theoretical amount of hydrogen chloride had been evolved. The mixture was cooled to yield a brittle foam which was powdered and reheated to 230°C to 240°C for 40 minutes under high vacuum. The mixture was then cooled again, ground to a powder, washed with cold dimethyl formamide followed by methanol and dried at 80°C for 2 hours under vacuum to yield 29 parts of a crystalline polymer. Infra-red analysis (by comparison with standard mixtures of homopolymers derived

from each of the polymerisable monomers) showed the product to contain 35% by weight of units having the structure



Analysis of the sulphur content of the polymer showed it to contain 36% by weight of these units.

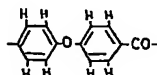
## EXAMPLE 23

41.7 parts of 4-phenoxybenzoyl chloride and 5.3 parts of diphenyl ether-4-sulphonyl chloride were melted together at 170°C and 2.5 parts of freshly sublimed ferric chloride were dissolved in the melt. After 2½ hours at 170°C, 86% of the theoretical amount of hydrogen chloride had been evolved and the

mixture was cooled, powdered and reheated to 240°C for 90 minutes under high vacuum (0.1 mm. Hg absolute pressure). The product was cooled, ground to a powder, washed with hot acetone and dried overnight at 90°C under vacuum to yield 36 parts of a polymer

partially soluble in nitrobenzene and soluble in 4,4'-diphenoxy diphenylsulphone at 200°C.

Infra-red analysis by the method described in Example 22 showed the polymer to contain 90% by weight of units having the structure



The polymer was highly crystalline, the crystal form being that of the homopolymer derived from 4-phenoxybenzoyl chloride.

following the process of Example 23 but using varying concentrations of monomers and catalyst. The concentrations of each monomer and the catalyst and the form of the products obtained are set out below.

#### EXAMPLE 24

A series of polymerisations was effected

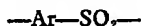
Experiment	Monomers*		Catalyst	Weight % of units from I in polymer	Form of polymer
	I	II			
A	37.0	10.7	2.2	78	Crystalline
B	32.4	16.1	2.4	67	Crystalline
C	23.2	26.7	1.8	46	Crystalline

\* I = 4-phenoxybenzoyl chloride

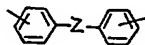
II = diphenyl ether-4-sulphonyl chloride

#### WHAT WE CLAIM IS:—

1. A thermoplastic polymeric material consisting essentially of repeating units having the structure

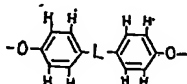


where Ar is a divalent aromatic residue which may vary from unit to unit in the polymer chain and in at least some of the units Ar has the structure I



(I)

(where Z is an oxygen or sulphur atom or the residue of a 4,4'-bisphenol having the structure II

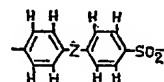


(II)

where L is  $-\text{CO}-$  or  $-\text{SO}_2-$  and in any other units Ar is a residue of benzene, diphenyl, or a polynuclear aromatic hydrocarbon containing not more than two aromatic nuclei, so that in the divalent aromatic residues containing two benzene rings each benzene ring bears one of the valencies, and one or more of the aromatically bound hydrogen atoms in any of the divalent aromatic residues may be replaced by halogen atoms or alkyl or alkoxy groups containing from 1 to 4 carbon atoms.

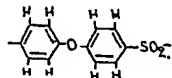
2. A polymeric material according to Claim 1 in which none of the aromatically bound hydrogen atoms in Ar has been replaced by other atoms or groups.

3. A polymeric material according to Claim 2 consisting essentially of repeating units having the structure

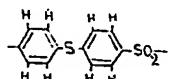


where Z is an oxygen or sulphur atom or the residue of a 4,4'-bisphenol having the structure II.

- 5 4. A polymeric material according to Claim 3 consisting essentially of repeating units having the structure

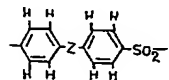


- 10 5. A polymeric material according to Claim 3 consisting essentially of repeating units having the structure



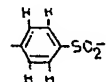
6. A polymeric material according to Claim 2 consisting essentially of repeating units having the structure

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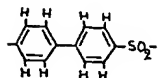


where Z is an oxygen or sulphur atom or the residue of a 4,4'-bisphenol having the structure II, and repeating units having the structures

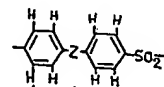
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and/or

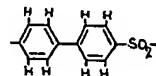


- 25 7. A polymeric material according to Claim 6 consisting essentially of repeating units having the structure



where Z is an oxygen or sulphur atom or the residue of a 4,4'-bisphenol having the structure II, and repeating units of the structure

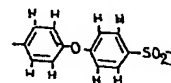
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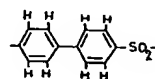
not more than 80 of every 100 units in the polymer chain having the latter structure

8. A polymeric material according to Claim 7 consisting essentially of repeating units having the structure

35



and repeating units having the structure



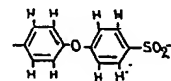
not more than 80 of every 100 units in the polymer chain having the latter structure.

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9. A modification of the polymeric material claimed in Claim 1 or Claim 2 in which some of the —SO<sub>2</sub>— linkages are replaced by —CO— linkages.

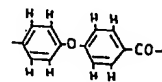
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10. A polymeric material according to Claim 9 consisting essentially of repeating units having the structure



and repeating units having the structure

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11. A polymeric material according to Claim 1, Claim 2 or Claim 9 having diphenyl ether units in essentially the all-*para* configuration.
- 5 12. A polymeric material according to any one of Claims 1 to 11 which contains no sulphonyl halide or carbonyl halide groups.
13. A polymeric material according to Claim 1, substantially as hereinbefore described and as illustrated by any one of Examples 1 to 11.
- 10 14. A polymeric material according to Claim 1, substantially as hereinbefore described and as illustrated by any one of Examples 12 to 15.
- 15 15. A polymeric material according to Claim 1, substantially as hereinbefore described and as illustrated by any one of Examples 16 to 18.
16. A polymeric material according to Claim 1, substantially as hereinbefore described and as illustrated by any one of Examples 19 to 21.
- 20 17. A polymeric material according to Claim 9, substantially as herein described and as illustrated by any one of Examples 22 to 24.
- 25 18. A fibre formed of a polymer as claimed in any one of Claims 1 to 17.
- 30 19. A film formed of a polymer as claimed in any one of Claims 1 to 17.
20. A moulded article formed of a polymer as claimed in any one of Claims 1 to 17.

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